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NON DESTRUCTIVE TESTING OF CREW ESCAPE SYSTEM SOLID ROCKET MOTORS FOR HUMAN SPACE APPLICATIONS

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Abstract

Non-destructive techniques (NDT) were used widely for defect detection in aerospace applications. Radiography and ultrasonic testing are most commonly used NDT methods in this area. Modern imaging techniques and new sources of radiation are widely used for catering to the challenging demands of various launch vehicle applications. In the present era of rocketry, human space programmes have a vital role in space exploration missions. The reliability of these missions have to be ensured through various ground tests and NDT techniques. Crew escape system (CES) is one of the most critical sub-systems in a human rated launch vehicle. It consists of solid motors which are sized and fired in such a way that the Crew Module (CM) is pulled away from the launch vehicle in case of an exigency at the launch pad or during ascent phase to a region outside the vulnerable zone without violating crew tolerance limits.

Based on the RT experience of different types of solid rocket motors, the NDT inspection plan of various special purpose motors have been made. The bonding at the interface of rocasin and metal interface is checked by ultrasonic testing. RT is carried out for finding any propellant / interface defects. The test plans and procedure were firmed up towards achieving maximum coverage of the motor considering the high reliability requirement. This paper describes the philosophy adopted in the preparation of plan and procedure for the radiography testing of solid motors for human space applications. The influence of various types of testing, job parameters, film characteristics etc. for imaging of defect, performance effectiveness and defect sizing are also discussed.

1. Introduction

Non-destructive evaluation, as the name implies, is the method of examining the integrity of a material/ medium without affecting the usability of the material. NDE assures that the material being probed contains no harmful discontinuities, thereby giving confidence to the end user in subjecting it to use under the influence of environment involving stress, temperature, vibration etc. Constant improvements done to the techniques have enhanced their capabilities not only in detecting flaws but also in other material characterization applications also. Selection of an NDE method is a complex task and depends upon several factors. A sound knowledge of the manufacturing process and the various types of flaws that can occur is the primary requirement before selecting an NDE method.

Crews escape system (CES consists of 4 different types of solid motors with specific objectives for each motor namely- Low Altitude Escape Motor (LEM), High Altitude Escape Motor (HEM), CES Jettisoning Motor (CJM) and Pitch Control Motor (PCM).

2. Purpose of Radiography

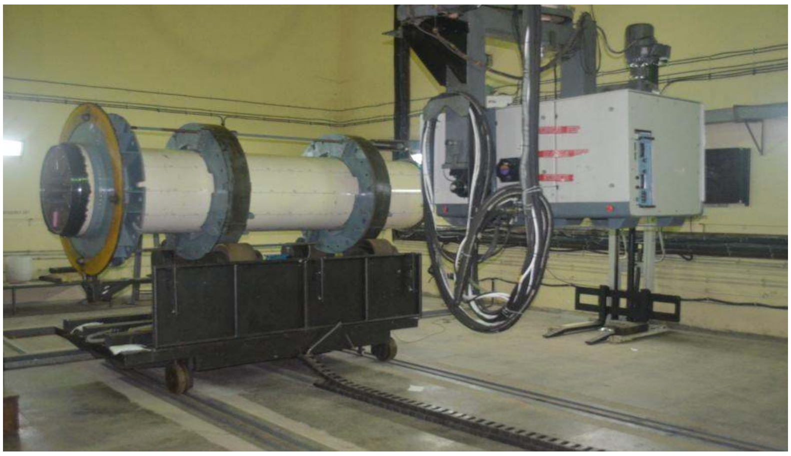


Figure 1: Radiography set up for LEM Propellant Grain

Propellant grain is subjected to radiography to detect defects, if any, such as voids, cracks, foreign material inclusions in the propellant, separation at the propellant/insulation/motor case interface etc. Radiography is the most suitable method to detect the above defects in the propellant. A 6MeV LINAC is used for radiography of the grain. After the removal of harnessing rings, the motor is positioned vertically / horizontally on the segment rotator for rotating and carrying out radiography. Figure -1 shows the radiography set up for LEM propellant grain.

2.2 Radiographic Technique

Large rocket motors above 300 mm diameter are inspected by high energy radiography techniques. Two types of radiographic techniques are employed for the radiography of these special purpose motors. 1. Through shots (normal shots) – double wall penetration- to detect defects such as voids, cracks, foreign material inclusions in the propellant grain 2. Tangential shots-to detect the separation, if any, at the interface of propellant/insulation/motor case, and also lf filling details. Several radiographic exposures are needed in the longitudinal and circumferential directions for inspecting a solid rocket motor. The number of exposures are determined based on the crack detection probability criteria and the criticality of defects at various regions. Considering the critical mission requirements of special purpose motors, stringent radiography testing plan is adopted for the detection and evaluation of the defect.

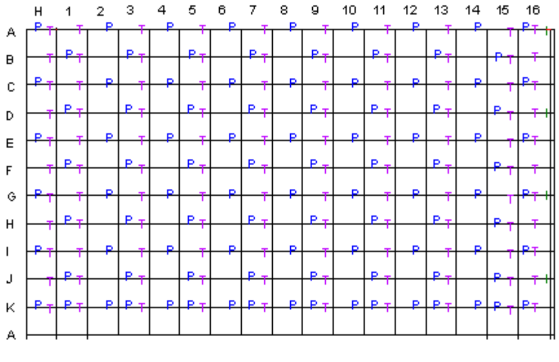
3. Radiography plan

Radiography plan reveals the number of shots required for radiography coverage and the orientation of the beam towards the object to be tested. The preparation of the plan is primarily based on the geometry of the object, the objective of test and criticality in the end use. The number of shots has to be defined with respect to the size of the component. For a cylindrical shaped rocket motor, shots are covered in both circumferential and longitudinal way. Since the special purpose motors undergo complex processing conditions, defects such as cracks, voids, debonds etc. May occur which may affect the ballistic and structural performance. Due to the criticality in the mission of special purpose motors, the marking plan of such motors should cover 100% scanning. The grain shots are covered in such a way that each lobes and valley of the motor shall be covered fully and the suitable contrast should be achieved by using multi-film techniques. This paper describes the philosophy adopted in the preparation of plan and procedure for the radiography testing of lem .

3.1 Marking Plan Of Low Altitude Escape Motor (Lem)

The crew escape system consists of lem which is sized and fired such that crew module is pulled away from the launch vehicle if there is an explosion or occurrence of any other undesirable event that can affect the safety of the mission at the launch pad or during the initial phase of flight. The motor has fabricated with 15cdv6 material having cylindrical shape.

Overall length of the segment is around 3500mm and diameter is around 750 mm. For the thermal protection, case is insulated with rocasin insulation and cast with propellant of multiple lobe star grain configuration. Harnessing rings are provided in the motor case for handling and transportation of the segment.



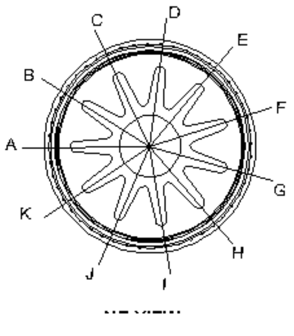


Figure 2: Marking plan for LEM Propellant Grain

The marking plan for typical special purpose propellant grain is as shown in the figure 2. The grain is divided into a number of circumferential segments (A, B, C….etc.) marked by lines A to K viewing from the head end of the grain in the clockwise direction. ‘A’ line is marked on the case corresponding to one valley. The grain is divided into several longitudinal sections (1, 2, 3…. etc.). Multiple exposures are taken at each longitudinal segment for the full coverage of propellant. Locations of tangential shots are marked by T, propellant shots by P and inhibition shots by I. Lay out for propellant & inhibition shots are shown in figure - 3. Tangential line in the middle of line A and B designated as AB. Inhibition shots designated as AN, DN, GN & JN.

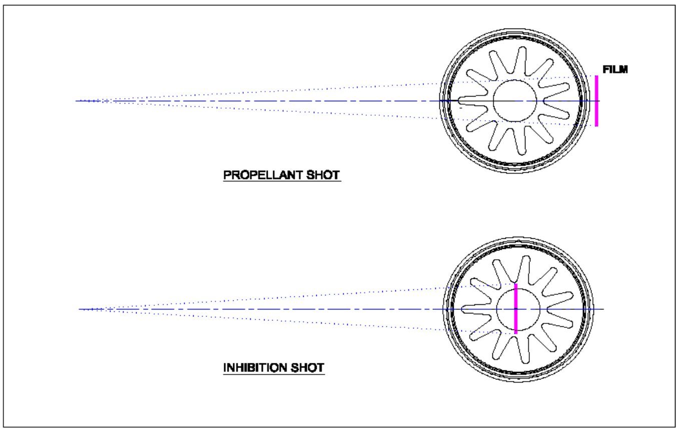


Figure 3: Sketch of propellant shot and inhibition shot

3.2 MARKING PLAN FOR PROPELLANT SHOTS

The major concern faced during the preparation of the grain shots is the typical star type port configuration of the motor. Due to the abrupt change in the geometry of the grain at port region, the chance of defects will be more. Since the 100% scanning of the grain is essential for ensuring the soundness of the motor, each grain shots have to be aligned with the valley and lobe of the grain. The subject contrast of the radiograph was adjusted by taking the shots inline with the valley and the lobe. Ray diagram for the grain is shown in figure - 4. Radiography of the solid propellant motors having small port area are designed using double wall single image technique. More than 100 grain shots are essential for the entire coverage of the grain. IQI of step hole type for getting the sensitivity of 2-2T is placed on the beam side of the segment for ensuring the quality of radiograph. Radiography film of D7 or equivalent is recommended for imaging.

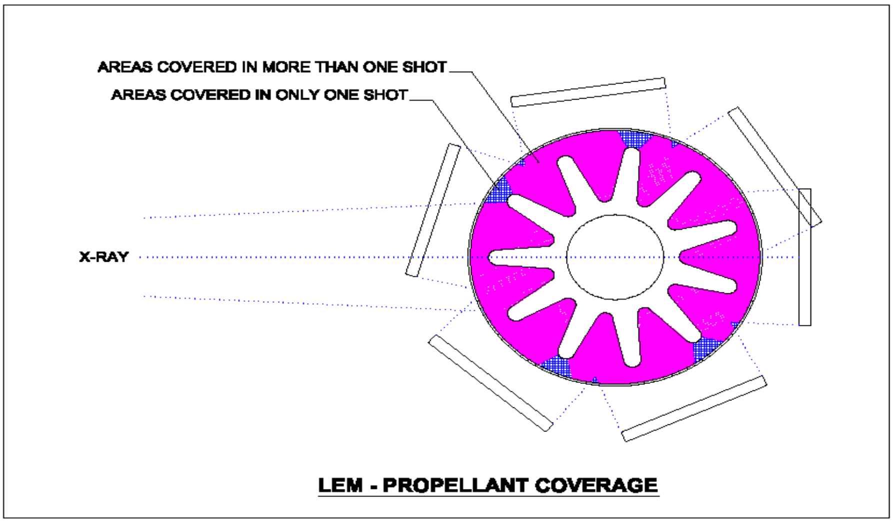

AREAS COVERED IN MORE THAN ONE SHOT
AREAS COVERED IN ONLY ONE SHOT
X-RAY
LEM - PROPELLANT COVERAGE

Figure 4: Sketch of ray diagram of propellant shots for LEM grain

3.3 Marking plan for tangential shots

Motor cases are insulated with ROCASIN insulation. The layers of insulation are designed according to the ballastic performance of the motor. Several layers of ROCASIN sheets are bonded together for achiving the desired insulation thickness. The integrity of the bond between the insulation and motorcase is significant for its performance. The propellant is cast inside the motor with suitable port configuration. Special type liner resin is applied over the ROCASIN insulation to esure the bonding of propellant with insulation material. Tangential shots are essential for the testing of interface details between motor case / insulation and propellant/insulation. Beam focusing is carried out at the critical interfaces.

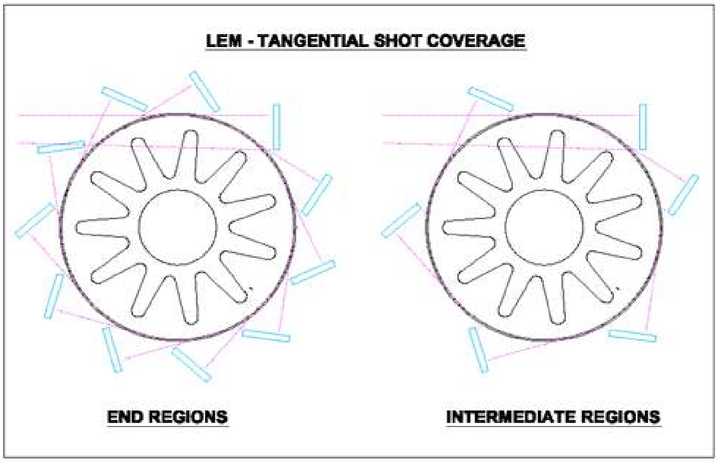


Figure 5: Sketch of ray diagram of propellant shots for LEM grain

For this special purpose motor more than 100 tangential shots are required. X-ray beam is focussed at the interface of each circumfernetial segments for the entire interfacial coverage of the motor. A single tangential shot is capable for the coverage of motor case/insulation interface and insulation/propellant interface. Sketch of ray diagram for tangential shots of LEM grain is shown in figure-5. Normally the tangential shots for other motors are taken in a random fashion only even if abrupt change in ROCASIN insulation thickness is there. The sagging effect of grain will be prodominent more in the port having star shaped grain configuration due to the variation of load concentration in lobe regions. Since the LEM motor is having star conguration 100% coverage of interfaces are essential. Marking plan for the tangential radiography of these motors are designed for catering to this requirement.

3.4 Marking plan for inhibition shots

Both ends of the solid rocket motors are inhibited with IR resin to arrest the undesirable radial burning of the propellant. The proper sealing of the propellant faces are made with pouring of inhibition resin in layers and cured in desired temperature. The intactness of the interface between propllant and inhibiton is assured by taking radiography using single wall single film image technique. The X-ray beam is focused at the inerface region and a lead marker is provided on the inhibiton joint at the port region. Four shots are required for the entire coverage of inhibiton. Due to the inheritant nature of IR resin, pores are generaly noticed in this region. Depending upon the optical density of the region of pores, the defects are being catagorised considering the high reliability requirement.

4. Exposure parameters

6MeV X-ray machine is sufficient for the radiography of the grains since the material thickness is less than for special purpose motors. The exposure conditions for the propellant shots are calculated from standard formula. For all exposures a source to film distance (FFD/SFD) of 4 m is used such that the geometrical unsharpness (Ug) produced by the radiographic set up is within the acceptable range. Before radiography, the port area of the grain is visually examined for any abnormalities. Proper lead identification letters are placed on the cassette outside the area of interest. The ends of the segments are indicated by lead arrows pointing towards head end of the grain in each radiograph.

Fast film with lead intensifying screens of 0.5/0.75 combinations are used for the radiography of these grains. The required X-ray energy and intensity are selected for the respective radiographs the thickness of the regions to be covered. To ensure the sensitivity of radiographs, step hole type IQI is used. This is made of Mg – Al alloy of density 1.78. Step thickness is 1 mm, 2 mm and 4 mm. Each step has a hole at the center region with diameter equal to the thickness. The desired sensitivity of special purpose motor is step hole of type 1-2T.

5. Interpretation of radiographs

Interpretation of the radiographs are carried out by viewing against a high intensity illuminator to detect defects in them. Additional exposures are taken to find extension of defect or to get more information. The optical density is measured using film densitometer. The accepted range of film density is 2.5 to 3.0. Mapping of the defects are carried out by taking additional exposures and the location of defects are defined by rotating the segment in increments. Various defect location techniques such as tube shift method lead marker method and triangulation techniques are explored for the evaluation of defects. Since the motor size is less than 1m, radial dimension of the void can be found out by taking tangential shots of the void region. In this method the void which was observed in the grain shot, rotated in small increments and finally positioned as tangent region. By taking the tangential exposure, the minimum distance between the void and the insulation and the distribution of the voids were obtained. In order to reveal the minute details of a particular region of the propellant, slow film having fine grain sizes are used. Any extension of the defects can be plotted by taking required tangent shots of that region.

6. Conclusion

Radiography is the best NDT tool for inspection of special purpose solid motors for human space applications. The choice of suitable and accurate radiographic technique and preparation of optimized shoot sketch is essential for effective defect detection. The test plans and procedure are made accordingly towards achieving maximum coverage of the motor considering the high reliability requirement. To meet the growing and challenging demands of launch vehicle applications, research and development in the field of radiography is improving with modern imaging techniques and new sources of radiation. By implementing the digital imaging system and the automation in object manipulators will reduce the duration for 100% radiography coverage of the special purpose motors of critical missions.

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